

A HIGH RESOLUTION X-RAY SPECTRUM OF THE LINER GALAXY M81

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ABSTRACT

We present the soft X-ray spectrum of the LINER galaxy M81 from a long observation with the *XMM-Newton* RGS. As well as continuum emission from the active nucleus, the spectrum shows emission lines from multi temperature collisionally ionized gas. The emission lines are significantly broader than the RGS point-source spectral resolution, and in the cross dispersion direction the emission lines are detected adjacent to, as well as coincident with, the active nucleus. This implies that they originate in a region of more than an arcminute (~ 1 kpc) spatial extent. A good fit to the whole RGS spectrum can be found using a model consisting of an absorbed power law from the active nucleus and a 3 temperature thermal plasma. Two of the thermal plasma components have temperatures of 0.18 ± 0.04 keV and 0.64 ± 0.04 keV, characteristic of the hot interstellar medium produced by supernovae; the combined luminosity of these two plasma components accounts for all the unresolved bulge X-ray emission seen in the *Chandra* observation by Tennant et al. (2001). The third component has a higher temperature ($1.7^{+2.1}_{-0.5}$ keV) and we propose X-ray binaries in the bulge of M81 as the most likely source of this emission.

Key words: X-rays: galaxies – ISM: supernova remnants – Galaxies: individual: M81 – Galaxies: active

1. INTRODUCTION

M81 is an Sab spiral galaxy hosting a low luminosity Seyfert nucleus which shows the characteristics of a “low ionization nuclear emission-line region” (LINER, Heckman 1980). It was first observed in X-rays with *Einstein* (Elvis and van Speybroeck 1982, Fabbiano 1988) which resolved several discrete sources in M81, the brightest of which is associated with its active nucleus. An apparently diffuse emission component associated with the bulge of M81, spatially extended over a few arcminutes was detected first with *Rosat* (Roberts and Warwick 2000, Immeler and Wang 2001) and later confirmed with *Chandra* data (Tennant et al. 2001). Spectra from *Rosat* (Immeler and Wang 2001), *BBXRT* (Petre et al. 1993), *ASCA* (Ishisaki et al. 1996) and *BeppoSAX* (Pellegrini et al. 2000)

suggested the presence of a soft (< 1 keV) thermal component in addition to an absorbed power law component from the nucleus. In this paper we present the soft X-ray spectrum of M81 at much higher resolution, from an observation with the *XMM-Newton* reflection grating spectrometer (RGS, den Herder et al. 2001).

2. RGS DATA AND SPECTRAL ANALYSIS

M81 was observed by *XMM-Newton* in April 2001 for a total of 138 ks. The RGS data were reduced using the *XMM-Newton* standard analysis software (SAS) version 5.2. The source spectrum was extracted from a region centred on the nucleus, enclosing 90% of the point spread function in the cross dispersion direction. Background regions were selected in the cross-dispersion direction so as to exclude 99% of the nuclear point spread function.

2.1. X-RAY EMISSION LINE GAS

Figure 1 shows the RGS spectrum. A number of prominent emission lines from H-like and He-like N, O, and Ne as well as L shell lines from Fe XVII and Fe XVIII are visible above the continuum; these are labelled in Figure 1. The lines are considerably broader than the RGS line spread function for a point source. For example, O VIII Ly α at ~ 19 Å is expected to have relatively little contamination from neighbouring lines, but a gaussian fit to this line shows that it is inconsistent with $\sim \sigma = 0$ at $> 99\%$. This broadening could be due to kinematic motions in the gas, for example if it is associated with the active nucleus. However a similar level of line broadening would result from the gas being extended over a region of ~ 2 arcminutes, because the RGS is a slitless dispersive spectrograph and its resolution is degraded for extended objects.

To distinguish these alternatives, we have examined the spatial distribution of the emission line gas in the RGS cross dispersion direction by constructing spectra in $40''$ wide strips at a range of distances from the nucleus of M81. A background spectrum was constructed from the average of the two most off-axis strips. The emission-line rich 14–20 Å parts of these spectra are shown in Figure 2. The emission line gas is extended over more than an arcminute implying that the excess broadening of the emission lines is due to their spatial extent rather than kinematic motions.

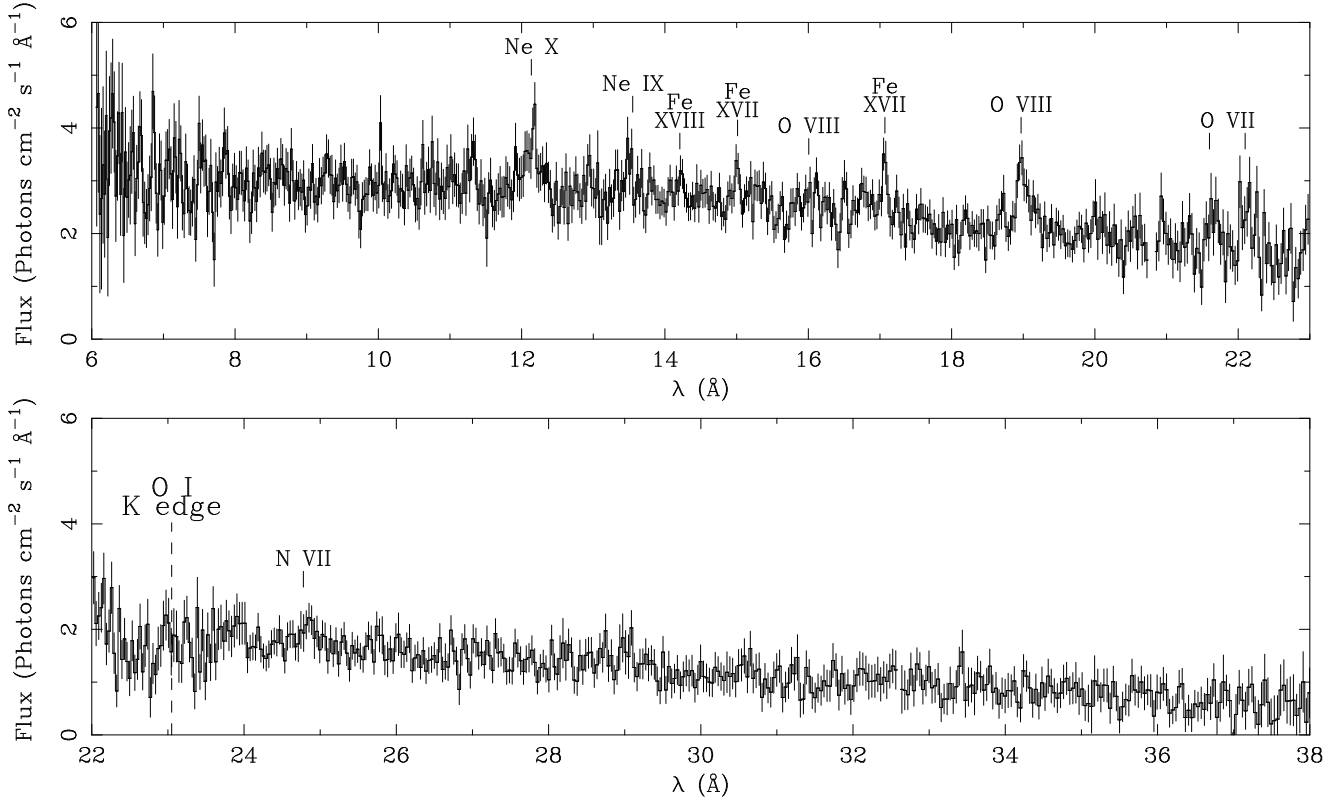


Figure 1. The RGS spectrum with prominent emission lines marked

We further investigate the nature of the emission line gas using plasma diagnostics from the He-like OVII triplet, as described in Pourquet and Dubau 2000. Taking the 21–23 Å portion of the RGS spectrum, we fitted the OVII lines as 3 gaussians with the relative wavelengths of the resonance (w), intercombination ($x+y$) and forbidden (z) lines fixed at their theoretical ratios. The best fit has an acceptable $\chi^2/\nu = 56/51$, and is shown superimposed on the 21–23 Å RGS spectrum in Figure 3a. In Figure 3b we show the confidence contour of the ($x+y+z$) against w line strength. The solid line shows the line ratio G ($= (x+y+z)/w$) = 4. Plasmas in which photoionization is the dominant ionization mechanism are expected to have ratios to the left of this line (i.e. $G > 4$); this is ruled out at 95% confidence in M81. In plasmas with line ratios to the right of this line, such as that seen in M81, collisional excitation is important and may be the dominant emission mechanism. Figure 3c shows confidence contours of the density diagnostic z against ($x+y$). The line shown on the plot corresponding to ratio R ($= z/(x+y)$) = 1 is excluded at $> 95\%$ along with all of parameter space to the right of this line, implying that the line emitting plasma has a density of $n_e < 10^{11} \text{ cm}^{-3}$.

2.2. MODELLING THE WHOLE RGS SPECTRUM

The emission lines in the soft X-ray spectrum of M81 are superimposed on a strong continuum from the its active nucleus. To reproduce this continuum emission we used XSPEC to fit a power law model, modified by both Galactic column and intrinsic absorption (xspec model TBabs of Wilms et al. 2000). We obtained a ($\chi^2/\nu = 1085/992$) for an intrinsic absorber with a column density of $N_H \sim 5 \times 10^{20}$. The fit parameters of this fit, and subsequent fits, are given in Table 1.

We next attempted to model the emission line component. As shown in Section 2.1 the O VII triplet is consistent with an origin in a collisionally ionized gas. We therefore began modelling the emission lines by adding a single temperature ‘Mekal’ thermal plasma to the absorbed power law model. This resulted in a significant improvement in the fit ($\chi^2/\nu = 876/990$) for a plasma temperature of 0.66 ± 0.04 keV. However, the emission lines are too narrow in this model, and some emission lines, most noticeably those from OVII, have much lower intensities in the model than in the observed spectrum. We therefore added a second, lower temperature, Mekal component to the model, and at both Mekal temperatures we added components with positive and negative velocities of 1500 km s^{-1} to reproduce the width of the lines caused by the spatial extent of the emission region. The relative normalisations of the rest, $+1500 \text{ km s}^{-1}$ and -1500 km s^{-1}

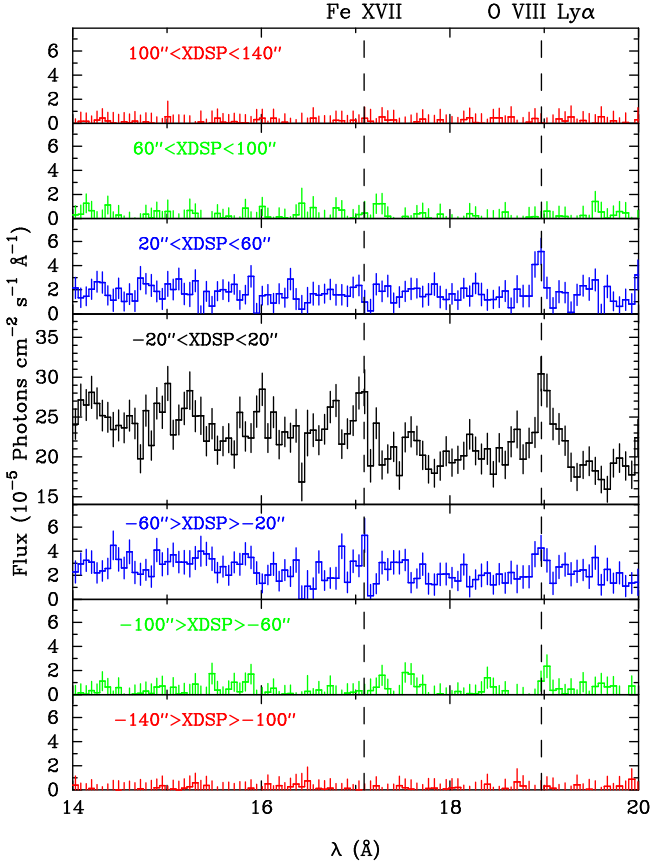


Figure 2. Spectral cuts in the cross dispersion direction showing that the line emission comes from a region that is extended in the cross dispersion direction

s^{-1} components were allowed to vary freely, but the temperatures were tied in the fit; the fluxes given for these model components in Table 1 are the totals for all three ‘velocity’ components. This resulted in a significant improvement in χ^2 , reproducing most of the emission lines well, with the second plasma component at a best fit temperature of ~ 0.2 keV. However, the blend of Ne X with Fe XXII-XXIII at ~ 12.1 Å is still underproduced by this model, and so a third, higher temperature, Mekal plasma was added. This resulted in another significant improvement in the fit, to a final $\chi^2/\nu = 803/980$, with a best fit temperature for the third Mekal component of $1.7^{+2.1}_{-0.5}$ keV. The model reproduces the spectrum well, as shown in Figure 4.

3. DISCUSSION

In Section 2.1 we showed that the soft X-ray emission lines in M81 come from an extended region. We also showed that the diagnostic OVII triplet is emitted by a low density region and is not powered by photoionization from the central AGN. Furthermore, in the previous section we showed that a 3 temperature thermal plasma model provides a good description of the emission line component

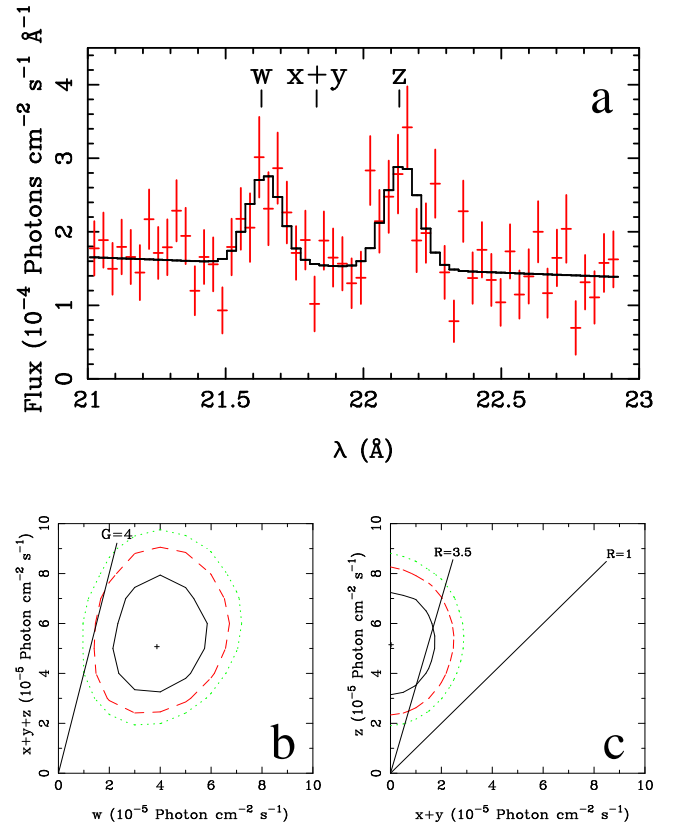


Figure 3. **a)** The O VII triplet and best fit model **b)** confidence contours (68%, 90% and 95%) for the strength of the OVII $x+y+z$ lines against the w line strength **c)** confidence contours for the OVII z line strength against the $x+y$ lines; see Section 2.1

of the M81 RGS spectrum in conjunction with absorbed powerlaw emission from the nucleus. Two of the thermal plasma components have temperatures of 0.18 ± 0.04 keV and 0.64 ± 0.04 keV, which are too low to be produced by accreting binaries, and are instead more characteristic of the hot interstellar medium produced by supernova explosions; in this case we would expect these emission lines to come from a genuinely diffuse region (or regions) in the bulge of M81.

The X-ray imaging study performed with *Chandra* does indeed find diffuse emission from the bulge of M81. The luminosity of this unresolved bulge emission reported by Tennant et al. (2001) is 8.6×10^{38} erg s^{-1} (0.2-8 keV) assuming a distance of 3.6 Mpc to M81. Assuming the same distance, the 0.18 keV and 0.64 keV thermal plasma components from our best fit model in Table 1 have luminosities of 2.2×10^{38} erg s^{-1} and 6.9×10^{38} erg s^{-1} respectively over the same energy range - sufficient to completely account for the unresolved bulge emission.

If the emission associated with the highest of the three plasma temperatures ($1.7^{+2.1}_{-0.5}$ keV) were also produced by a hot interstellar medium, or by a large population of very

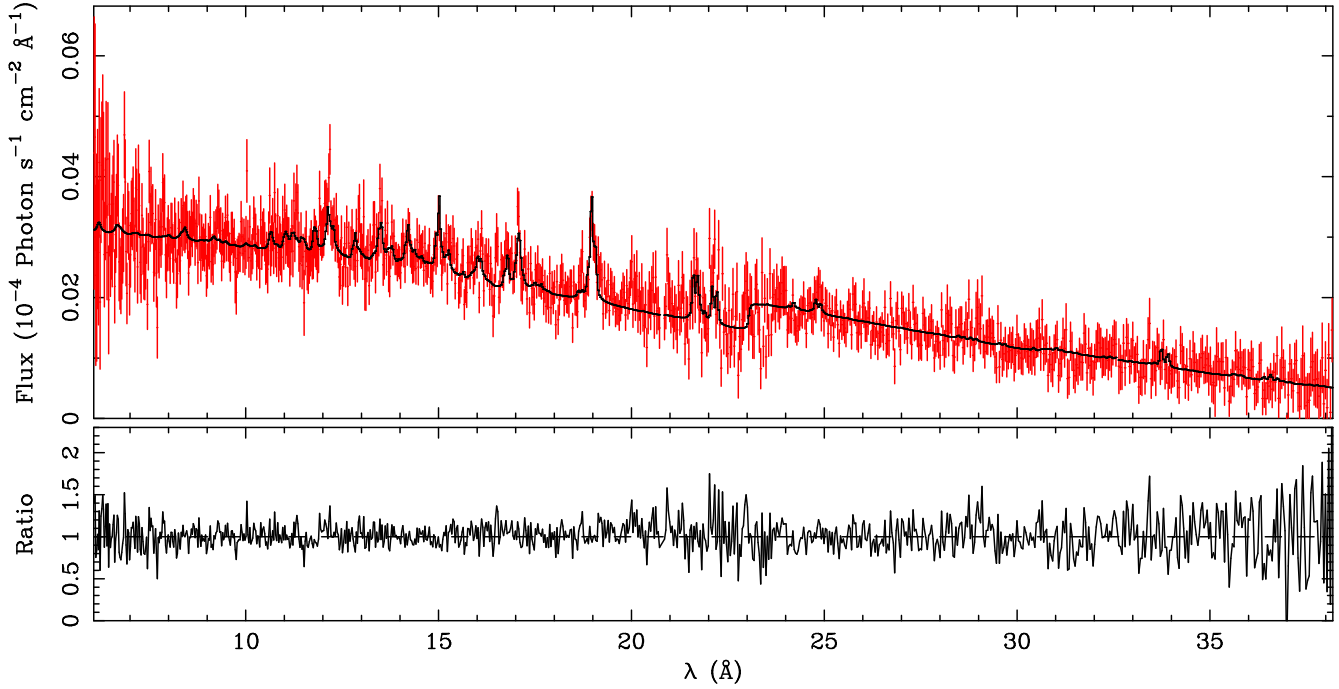


Figure 4. Power law + intrinsic neutral absorption + 3 mekal model fit to the RGS spectrum. The top panel shows the model (black line) and the data (red points). The bottom panel shows the data/model ratio

Table 1. Spectral fitting of the whole M81 RGS spectrum

(1) Model	(2) Γ or kT	(3) flux	(4) N_H	(5) χ^2/ν
PL \times N_H	2.06 ± 0.06	99.9 ± 3.8	4.8 ± 0.8	1085/992
PL \times N_H +Mek	1.94 ± 0.07 0.66 ± 0.04	95.8 ± 3.7 $4.3^{+0.9}_{-0.7}$	3.3 ± 0.8	876/990
PL \times N_H +Mek3 +Mek3	1.93 ± 0.07 $0.20^{+0.04}_{-0.02}$ 0.66 ± 0.05	94.5 ± 3.8 1.5 ± 0.5 $4.2^{+0.8}_{-0.7}$	3.4 ± 0.8	821/984
PL \times N_H +Mek3 +Mek3 +Mek3	1.94 ± 0.06 0.18 ± 0.04 0.64 ± 0.04 $1.7^{+2.1}_{-0.5}$	$91.6^{+7.4}_{-4.4}$ $1.1^{+0.5}_{-0.4}$ $4.2^{+0.8}_{-0.9}$ $3.4^{+7.6}_{-2.2}$	3.4 ± 0.8	803/980

Explanation of columns:

- 1 PL = power law,
NH = neutral absorber ('tbabs' model in XSPEC),
Mek = thermal plasma ('Mekal' model in XSPEC),
Mek3 = thermal plasma ('Mekal' model in XSPEC) with components at ± 1500 km s $^{-1}$ to the broadening of the lines produced by the spatial extent of the emission.
- 2 power law photon index or temperature of thermal plasma (keV)
- 3 flux of model component in the energy range 0.3-2.0 keV, in units of 10^{-13} erg cm $^{-2}$ s $^{-1}$ after correction for Galactic absorption of $N_H = 4.16 \times 10^{20}$ cm $^{-2}$
- 4 intrinsic neutral column density (cm $^{-2}$).

low luminosity sources such as cataclysmic variables, it would also appear diffuse in the *Chandra* imaging. However, the two lower temperature plasma components alone completely account for the unresolved emission, and hence the higher temperature emission must arise in part of the bulge population resolved by *Chandra*. We propose X-ray binaries as the most likely origin of the higher temperature emission.

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